Appendix N

Delfin LNG Revised Underwater Acoustic Modeling Analysis

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To: William Daughdrill, Director, Health, Safety and Environment, Fairwood Peninsula Energy Corporation

From: Jeffrey Martin, Senior Technologies Manager, Ocean Sound and Marine Life Services, CSA Ocean Sciences Inc.

Re: Impact Calculations

Injury and behavior zones of influence (ZOI) were calculated based on unmitigated source levels for impact-driven 78-inch steel pipe pilings. Affected area radii representing potential behavioral disruption to fish and marine mammals were calculated using the root mean square (rms) of the anticipated sound pressure level (SPL) at the source.

SPL_{rms} is primarily used in the assessment of the effects of underwater sound on marine mammals and fish. The SPL_{rms} is the square root of the sum of the squares of the pressure contained within a defined period from the initial time to a final time (**Equation 1**). (Caltrans 2009, Robinson et al., 2014).

Equation 1:

$$SPL_{rms} = \left[\frac{1}{t_f - t_i}\int_{t_f}^{t_i} p^2\,(t)dt\right]^{1/2}$$

Where:

p^2 = pressure;
d = difference;
t_i = initial time; and
t_f = final time.

Further, Sound Exposure Level (SEL) is the constant sound level in one second, which has the same amount of acoustic energy as the original time-varying sound (i.e., the total energy of an event). SEL is calculated by summing the cumulative pressure squared over the time of the event. The accumulation of exposure over a designated period of time or number of instances of a sound is termed Cumulative SEL (cSEL). cSEL is used for injury metrics in fish (GARFO, 2016) and in newer impact metrics for marine mammals (NOAA 2016). cSEL can be estimated from a representative single-strike SEL value and the number of strikes that likely would be required to place the pile at its final depth by using the following equation:

$$cSEL = SEL + 10 \log (\#\ of\ pile\ strikes)$$

It was estimated in the original application that 3600 pile strikes would occur per day.

To determine the affected area, the transmission loss (TL) of the sound was computed across varying ranges from the source. The practical spreading equation (**Equation 2**) was used to determine the amount of sound loss.

Equation 2:

$$TL = 15 \log_{10} r$$

Where: r = range (m).

In order to determine propagation distances, the source SPL must be determined. No directly comparable SPL measurement references were found for the proposed 78-inch steel pile. Therefore, measurements from piling of 96-inch Cast-in-Steel-Shell (CISS) piles for the Benicia-Martinez Bridge were used as proxies for the impact analysis (ICF Jones & Stokes and Illingworth and Rodkin Inc. 2009; Caltrans 2015). In order to account for the smaller pile diameter considered in this analysis, the 96-inch proxy measurements were reduced by 5dB to estimate the source level of the 78-inch piles. This modified source level was then carried through the propagation calculations to determine impact radii (**Table 1**). This follows the guidance set forth in the NMFS pile driving impact calculation guidance (GARFO, 2016). No other modifications in the calculations were made

Table 1. Estimated sound pressure levels produced by a 78-inch steel pile calculated for seven propagation distances

Propagation distance for 78-inch steel pile	$SPL_{0\text{-}p}$ (dB re 1µ Pa)	SPL_{RMS} (dB re 1µ Pa)	SEL (1-sec dB re 1µ Pa)
5 meters	220	205	194
10 meters	215	200	189
20 meters	210	195	184
50 meters	205	190	179
100 meters	200	185	174
500 meters	190	175	164
1000 meters	185	170	159

The SPLs selected for the ZOI radii calculations are based on accepted threshold criteria described in **Table 2**.

Table 2. Threshold levels used to determine ZOI radii.

Criterion	Definition	Metric	Threshold
Cetaceans[1]			
Behavior	Impulsive source	SPL_{rms}	160 dB re 1 µPa
Injury	Impulsive source	SPL_{rms}	180 dB re 1 µPa
Fish[2]			
Behavior	Impulsive or continuous source	SPL_{rms}	150 dB re 1 µPa
Injury	Peak sound pressure level (SPL_{peak})	SPL_{peak}	206 dB re 1 µPa
Injury	Injury >2 g fish size for cumulative sound exposure level over 12 hours	SEL_{cum}	187 dB re 1 $\mu Pa^2 \cdot s$
Injury	Injury <2 g fish size for cumulative sound exposure level over 12 hours	SEL_{cum}	183 dB re 1 $\mu Pa^2 \cdot s$

1. Based on current regulatory criteria (NOAA, 2005). Newer threshold criteria is currently proposed by NMFS (NOAA 2016) but have not yet been accepted for regulatory purposes.
2. Based on GARFO 2016, available at: http://www.greateratlantic.fisheries.noaa.gov/protected/section7/guidance/consultation/index.html

The calculated propagation radii for an unmitigated 78-inch steel pile are listed in **Table 3** and graphically displayed in **Figures 1** through **5.** The figures are shown to visually represent the calculations described above. Other parameters that influence the propagation and attenuation of sound underwater such as water depth, sediment type, sound speed profile, etc. were not accounted for in this exercise.

Table 3. Estimated distances to species threshold levels for an unmitigated 78-inch pile

	Onset of physical injury			**Onset of behavioral effects**
FISH	**Distance to 206 dB (SPL_{peak})**	**Distance to cSEL of 187 dB (injury for fish >2g)**	**Distance to cSEL of 183 dB (injury for fish <2g)**	**150 dB_{rms}**
Distance from source (78" Steel Pile)	40 m	3193 m	3,981 m	21,544 m
CETACEANS	**180 dB_{rms}**			**160 dB_{rms}**
Distance from source (78" Steel Pile)	215 m			4,642 m

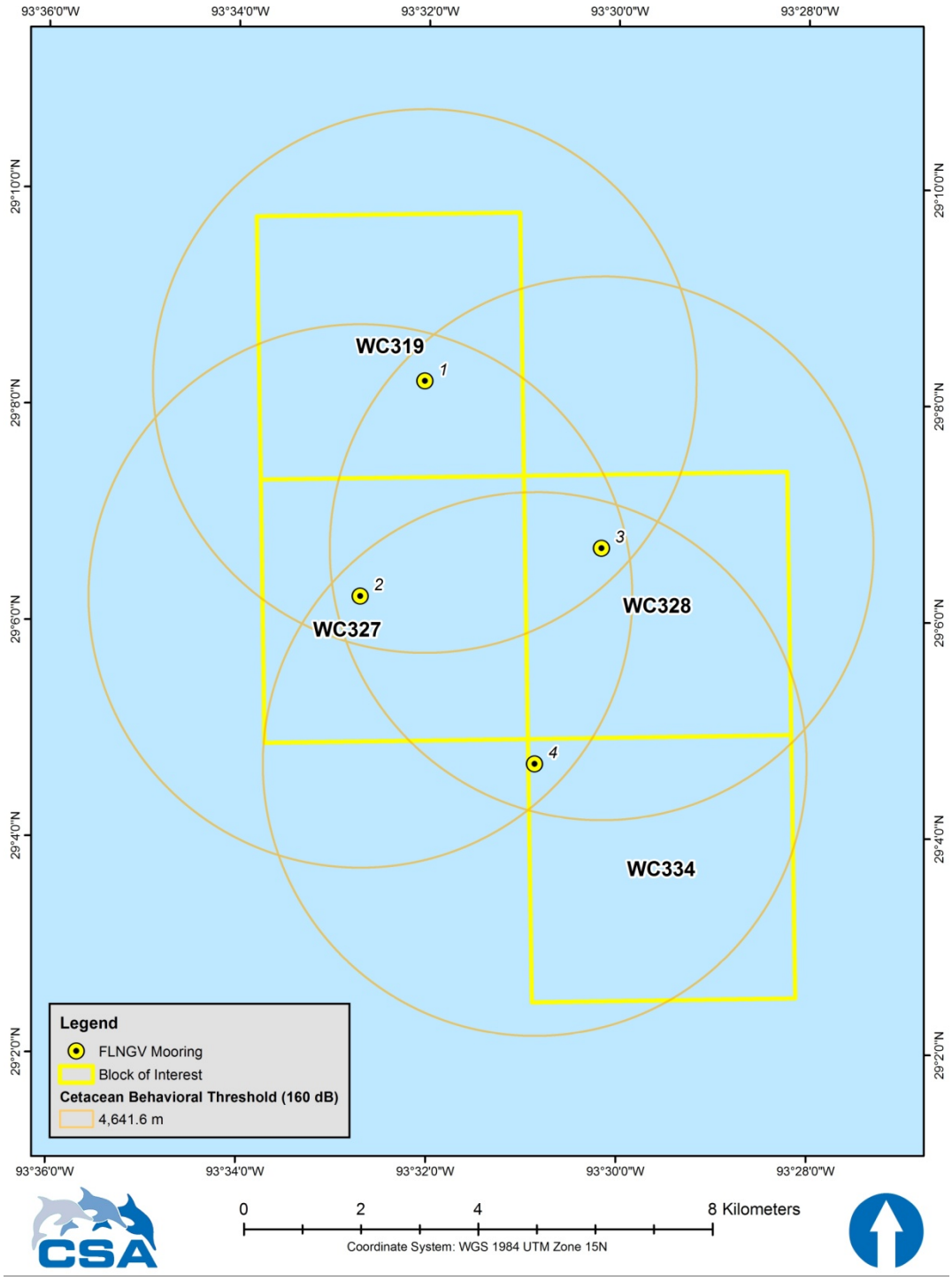

Figure 1. Cetacean behavioral threshold radii for the160dB$_{rms}$ isopleths surrounding the pile locations. The noise propagation distances depicted are based on a non-mitigated impulsive source.

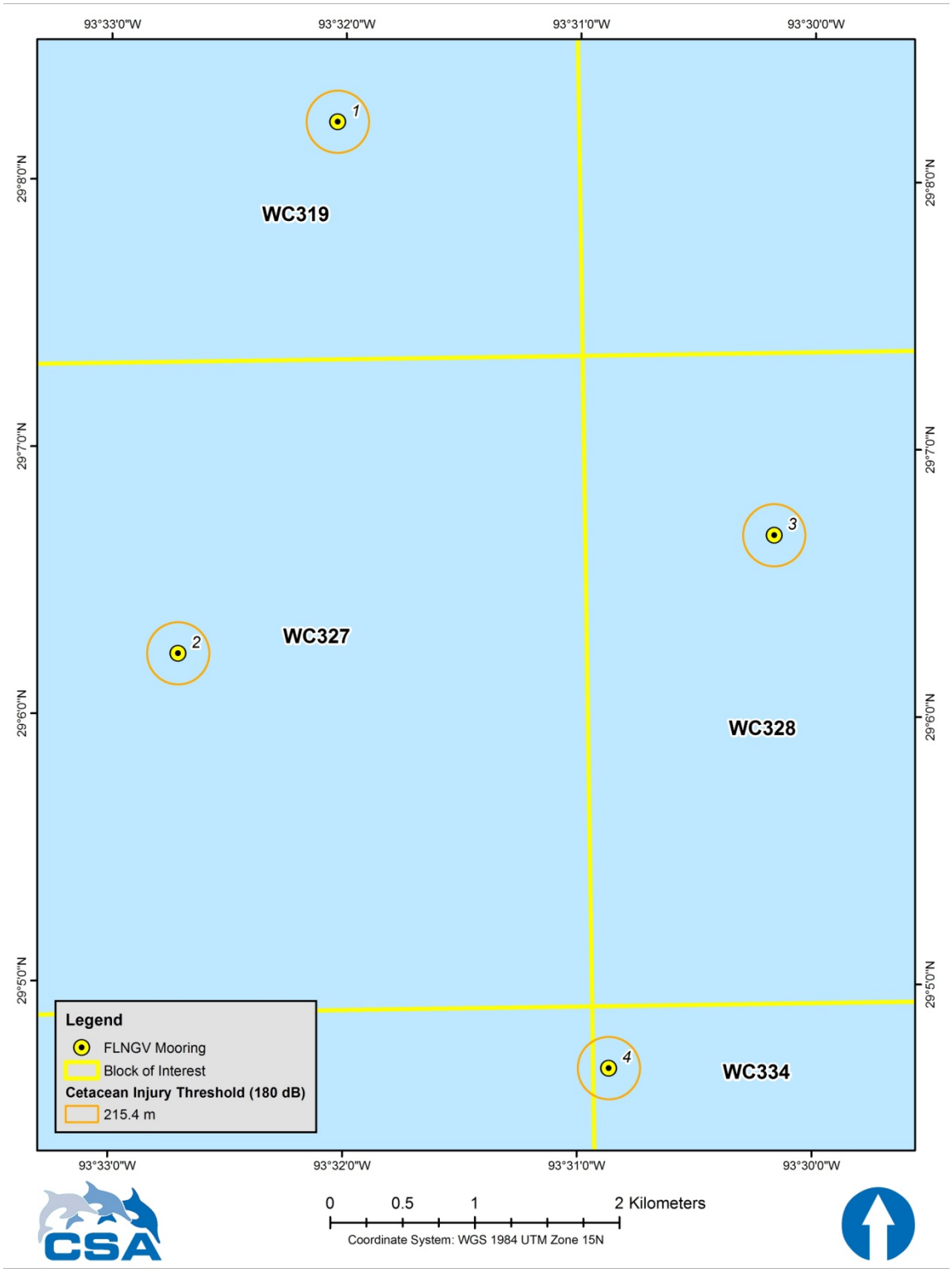

Figure 2. Cetacean injury threshold radii for the180dB$_{rms}$ isopleths surrounding the pile locations. The noise propagation distances depicted are based on a non-mitigated impulsive source.

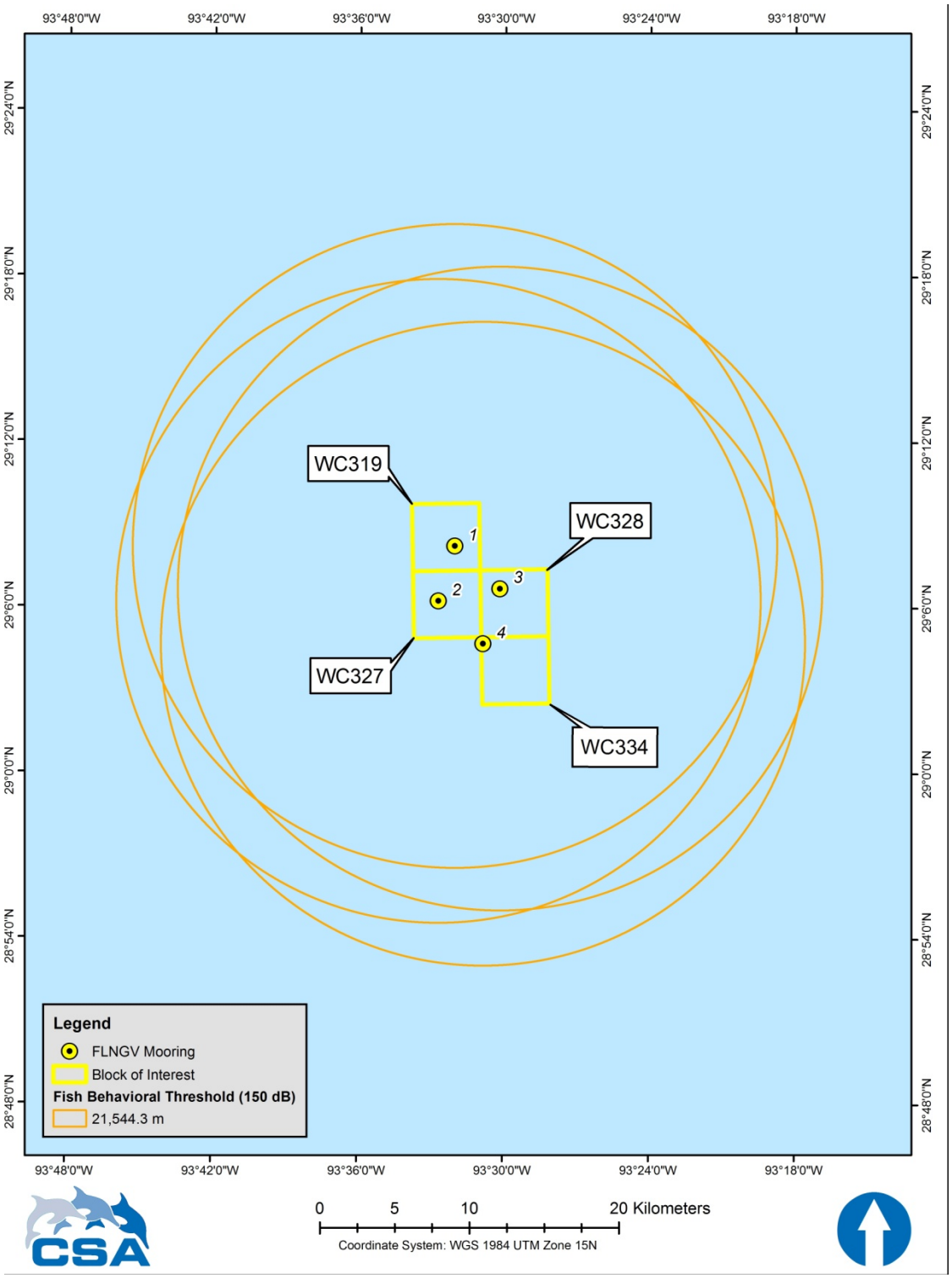

Figure 3. Fish (based on calculations for salmonids and sturgeon) behavioral threshold radii for the150dB$_{rms}$ isopleths surrounding the pile locations. The noise propagation distances depicted are based on a non-mitigated impulsive source.

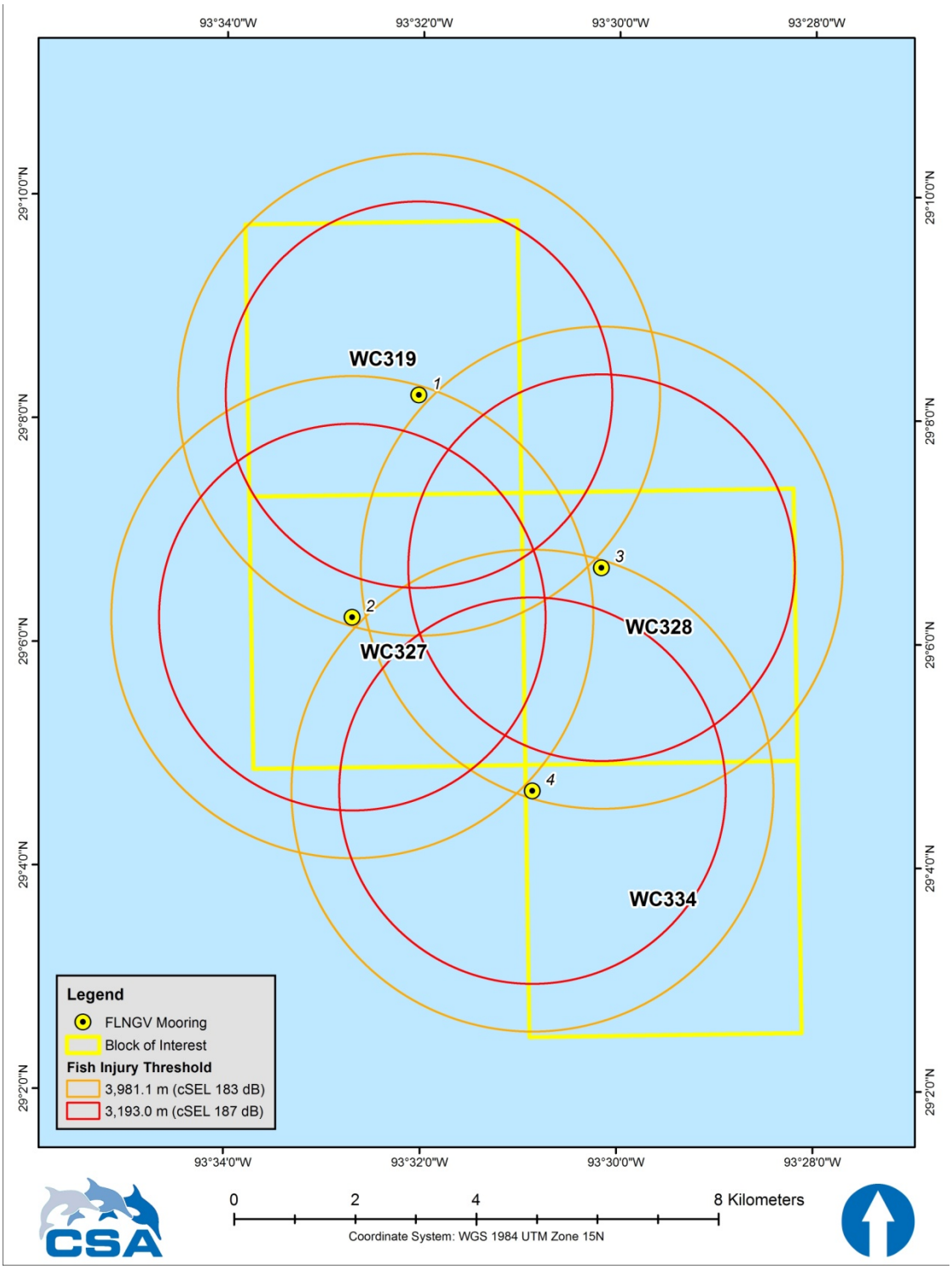

Figure 4. Fish injury threshold (based on calculations for salmonids and sturgeon) radii for cumulative sound exposures. The 187 dB and 183 dB isopleths surrounding the pile locations relate to injury thresholds for fish weighing greater than 2g and fish weighing less than or equal to 2 g. respectively. The noise propagation distances depicted are based on a non-mitigated impulsive source.

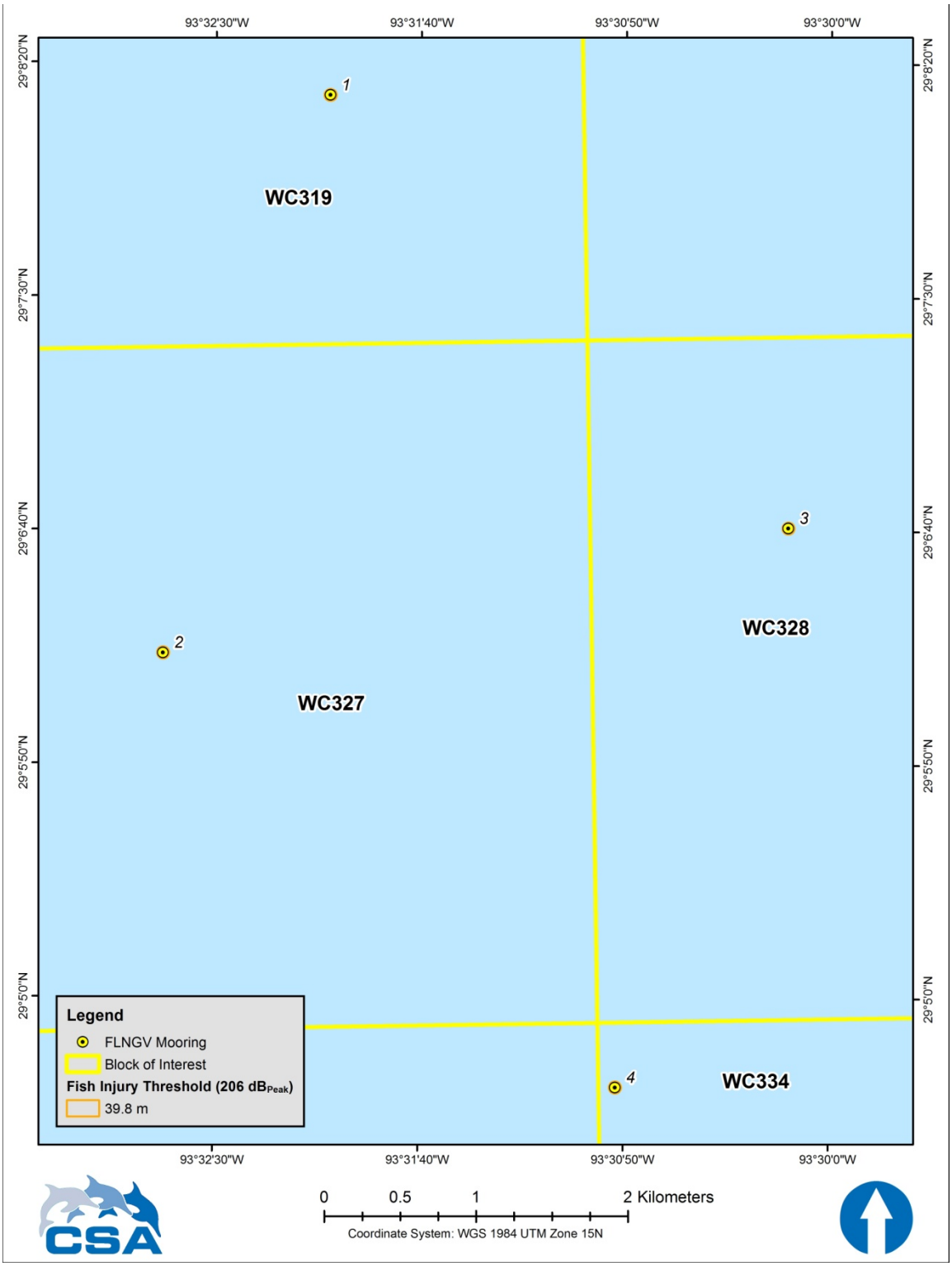

Figure 5. Fish injury threshold (based on calculations for salmonids and sturgeon) radii for the 206dB$_{peak}$ isopleths surrounding the pile locations. The noise propagation distances depicted are based on a non-mitigated impulsive source.

REFERENCES

California department of transportation (Caltrans). 2015. Technical guidance for assessment an mitigation of the hydroacoustic effects of pile driving on fish. Report No CTHWANP-RT-15-306.01.01. November.

ICF Jones & Stokes and Illingworth and Rodkin Inc. 2009. Final technical guidance for assessment and mitigation of the hydroacoustic effects of pile driving on fish. Prepared for the California Department of Transportation.

Greater Atlantic Region Fisheries Office (GARFO). 2016. GARFO Acoustics Tool: Analyzing the effects of pile driving on ESA-listed species in the Greater Atlantic Region. Available at: http://www.greateratlantic.fisheries.noaa.gov/protected/section7/guidance/consultation/index.html

National Oceanographic and Atmospheric Administration (NOAA). 2005. Interim sound threshold guidance. Available at: http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html

National Oceanographic and Atmospheric Administration (NOAA). 2016. Document containing proposed changes to: Draft guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic threshold levels for onset of permanent and temporary threshold shifts. Available at: http://www.nmfs.noaa.gov/pr/acoustics/draft_guidance_march_2016_.pdf

Robinson, S. P., P. A. Lepper, and R. A. Hazelwood. 2014. Good Practice Guide for Underwater Noise Measurement. National Measurement Office, Marine Scotland, The Crown Estate. NPL Good Practice Guide No. 133, ISSN: 1368-6550